Discovery of fundamental particle concludes long-standing scientific quest

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On July 21 scientists at the Fermi National Accelerator Laboratory near Chicago reported the discovery of the tau neutrino, marking the conclusion of the scientific quest to discover the 12 fundamental particles which make up matter. An international team of 54 physicists working in the United States, Japan, South Korea and Greece used the powerful particle accelerator, the Tevatron, to make the discovery. A spokesman for the scientific team, Byron Lundberg, stated, “We finally have direct evidence that the tau neutrino is one of the building blocks of nature. It is one thing to think there are tau neutrinos out there. But it is a hard experiment to do.”

The tau neutrino is the third type and most elusive of the neutrinos to be discovered. The particles are produced by the sun and are thought to be relatively common but have proved extremely difficult to detect as they have no charge, little or no mass and pass through most matter without leaving a trace. It is estimated that only one in 10 billion neutrinos traveling through the earth would react with an atomic nucleus. It is only when such a collision occurs that evidence of the neutrino's presence can be observed.

The original experiment was carried out in 1997 and involved the production of an intense beam of neutrinos, which contained some tau neutrinos. The beam crossed a one-meter-long target of iron plates sandwiched with layers of emulsion designed to record the particle interactions. The various particles leave distinctive tracks within the emulsion which are recorded using special scanning devices with computer controlled video cameras. It took three years to analyse the massive amount of resulting data.

The tau neutrino leaves a track when it collides with an atomic nucleus to form a tau lepton (another fundamental particle), which leaves a short trail with a kink indicating the decay of the tau lepton. Lundberg commented: “It was the proverbial needle in a haystack. The ... experiment recorded six million potential interactions. By analyzing signals from various components of the 50-foot-long detector, they winnowed out all but 1,000 candidate events. Of these, four events provided evidence for the tau neutrino.”

The existence of neutrinos was first proposed by the Austrian theoretical physicist Wolfgang Pauli in 1930 in his examination of a form of radioactive decay known as beta decay. In this process an electron is emitted from an atomic nucleus, but with a portion of the original energy and momentum of the combined particles missing. In order to maintain the laws of energy conservation, Pauli hypothesised that another, undetected, particle was being emitted, carrying off the missing energy.

This was further elaborated in 1934 by Italian physicist Enrico Fermi, who named the particle. Three types of neutrino are known to exist. The electron neutrino was first discovered in 1956, while the second, the muon neutrino, was detected in 1962. The electron and muon neutrinos are easier to produce and detect than the tau neutrino. Scientists have only recently been able to obtain high enough energy levels to create tau neutrinos.

Scientists became alerted to the existence of the third, tau neutrino in 1977 with the discovery of the tau lepton. A lepton is one of six fundamental particles, three charged and three neutral. The electron is the most commonly known lepton. Each of the charged leptons is known to have a corresponding neutrino. In 1989 scientists at the European Organisation for Nuclear Research (CERN) in Switzerland proved the tau neutrino was the third and last of the neutrinos, although a direct observation still remained technically impossible.

The tau neutrino is one of the particles of the Standard Model. This was devised by physicists over several decades to explain the fundamental composition and evolution of matter from its origins in the big bang to its current state. There are two types of particles: the matter particles called leptons and quarks, and the force-carrying particles called bosons. Scientists use an instrument known as a particle accelerator to accelerate particles to just below the speed of light and then smash them into other particles. The collision causes the atoms to disintegrate into more basic particles.

The energy of the collision is designed to approximate the energy levels immediately after the big bang. In the initial stages of the big bang the universe existed in a highly compressed state. The initial expansion resulted in a decrease in the density and temperature of matter and many of the fundamental particles, which were to later combine to form nuclei, existed as free entities. About a million years later the universe cooled sufficiently to allow the formation of complete atoms. The greater the energy produced in the particle accelerator the closer the approximation to the period after the big bang.

The discovery of the tau neutrino will enable scientists to confirm whether or not the particle has mass. According to the Standard Model, neutrinos are not supposed to have any mass at all. However, an experiment conducted two years ago in Japan indicated they had a very small mass. Such a confirmation will not only require a fundamental reassessment of the Standard Model but would be critical in scientists' view of the likely evolution of the universe.

Neutrinos are known to exist in such large quantities that if they possess even a minuscule mass scientists' estimation of the overall mass of the universe would be radically altered. The additional mass, carrying with it additional gravitational attraction, would allow scientists to explain how galaxies are held together. This would have major implications for estimates of the rate of expansion of the universe and its long-term trajectory. Experiments are currently being conducted in Japan, CERN and the Fermilab to determine the mass of the neutrino.

Scientists are also intensifying their hunt for the Higgs boson, a force particle which is thought to account for mass. It is not certain whether the current generation of particle accelerators have sufficient energy to detect the Higgs boson, but the CERN Large Hadron Collider, due to come into operation in about 2005, will probably be able to complete the task.

Such experiments not only play a crucial role in developing a more complete understanding of the makeup of matter but give a deeper insight into the evolution of the universe.